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Cloud Changes over the Pacific Using A-train Measurements

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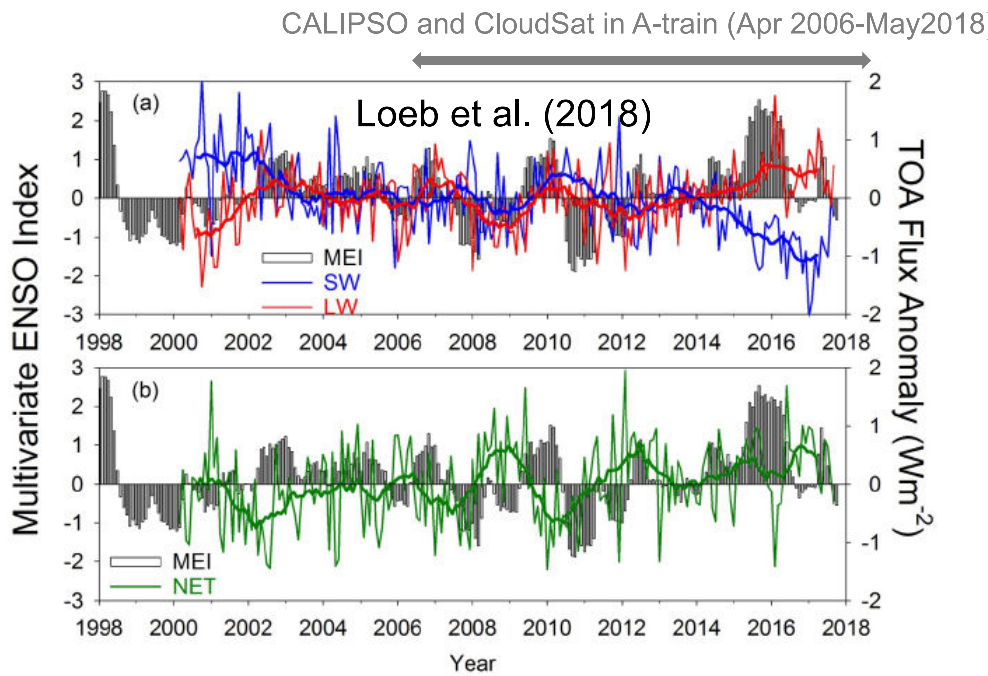
Background

- From A-train observations, more than 18 years of CERES and MODIS data are available, and more than 11 years of CALIPSO and CloudSat data are available. This enables us to examine cloud changes for the period longer than a decade.

- According to Loeb et al. (2018), there was a significant SW anomaly trend from 2014 to 2017, which were largely driven by low cloud anomalies.

- Therefore, it is interesting to examine long-term cloud changes using CERES, CALIPSO, CloudSat, and MODIS.



Datasets

- ❑ CERES **EBAF Ed4.1** flux dataset
- ❑ MODIS (Passive sensor) cloud properties: **CERES Ed4A SSF** Aqua hourly data
- ❑ CALIPSO (Lidar) cloud properties: **CALIPSO V4 VFM** product
- ❑ CloudSat (Radar) cloud properties:

  CloudSat R05 2B-GEOPROF, 2B-CWC-RO, 2C-ICE
- ❑ CloudSat + CALIPSO (Radar+Lidar) cloud properties:

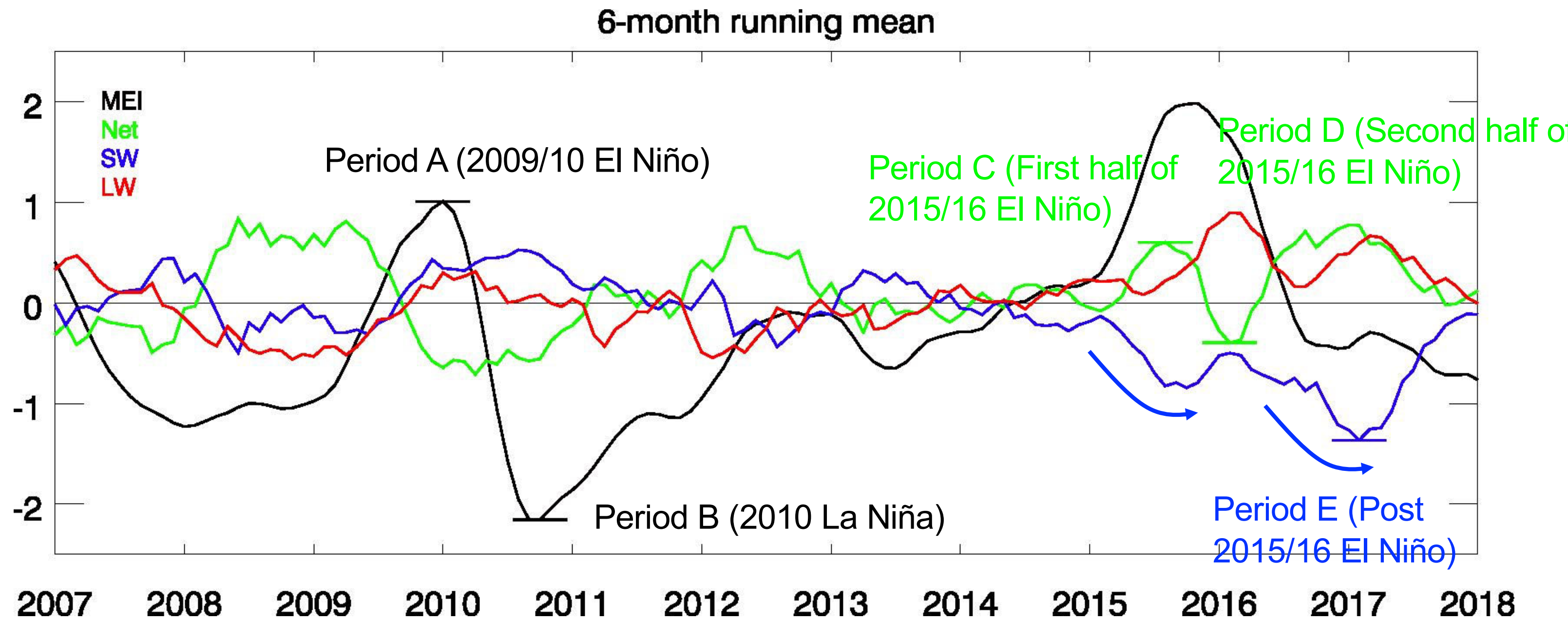
  Combination of CloudSat R05 and CALIPSO V4 based on Kato et al. (2010)
- ❑ Meteorological properties: **MERRA-2**, ERA-5

  Sea surface temperature (SST), temperature, humidity, and vertical velocity

- *CloudSat has been operating for daytime only since June 2012, and for the consistency, cloud properties for daytime are analyzed for all cloud datasets. Also we use MODIS SSF Aqua for consistent sampling with CloudSat and CALIPSO.*

Five Periods of Interest from 2007 to 2017

Period	Note	MEI mean	SW outgoing anomaly (Wm^{-2})	LW outgoing anomaly (Wm^{-2})	Net incoming anomaly (Wm^{-2})
A: Oct 2009–Mar 2010	2009/10 El Niño	**+1.01**	+0.34	+0.30	+0.64
B: July 2010–Dec 2010	2010 La Niña	**–2.16**	+0.48	+0.08	–0.56
C: May 2015–Oct 2015	2015/16 El Niño	+1.87	–0.83	+0.22	**+0.60**
D: Nov 2015–Apr 2016	2015/16 El Niño	+1.64	–0.50	+0.90	**–0.40**
E: Nov 2016–Apr 2017	Neutral	–0.35	**–1.36**	+0.59	**+0.77**



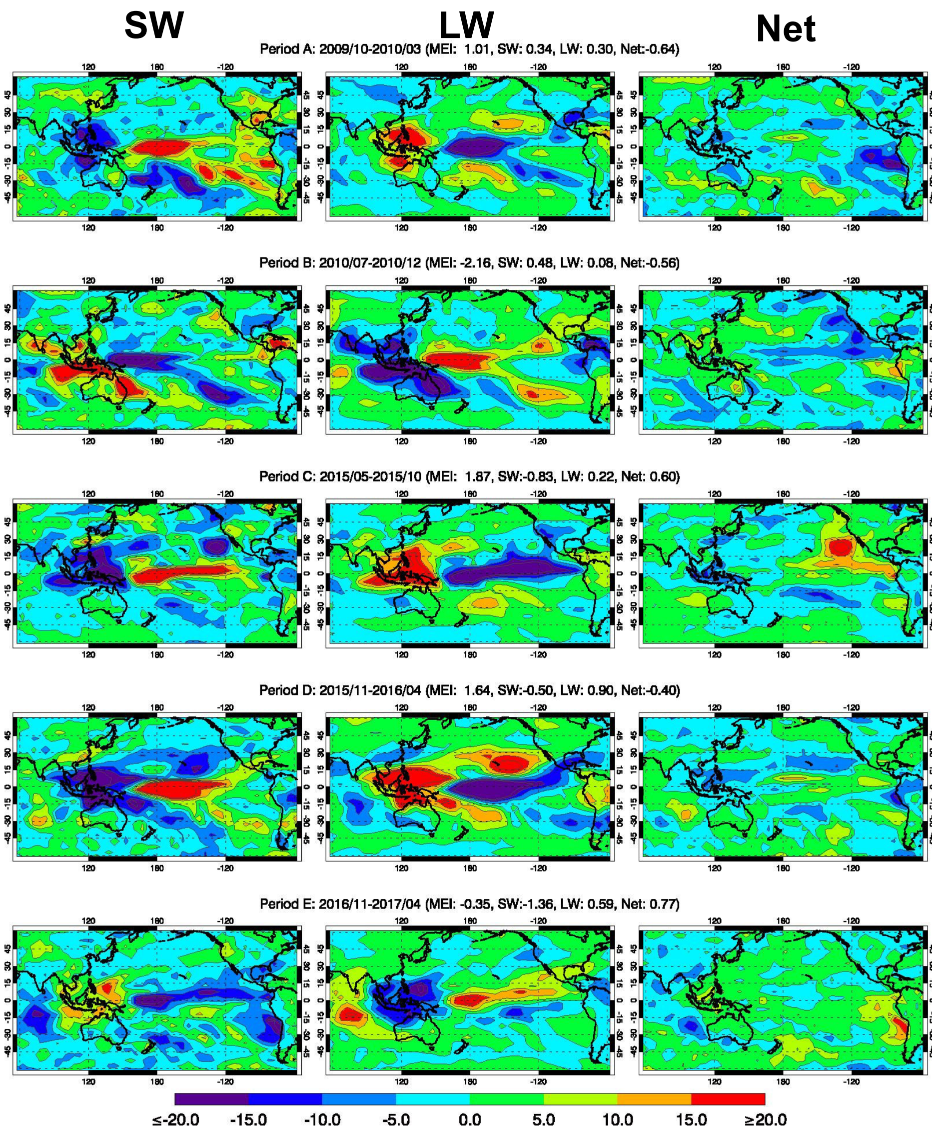
Period A
(2009/10 El Niño:
Oct 2009 – Mar 2010)

Period B
(2010 La Niña:
Jul 2010–Dec 2010)

Period C
(First Half of
2015/16 El Niño:
May 2015–Oct 2015)

Period D
(Second Half of
2015/16 El Niño:
Nov 2015–Apr 2016)

Period E
(Post 2015/16 El Niño:
Nov 2016–Apr 2017)

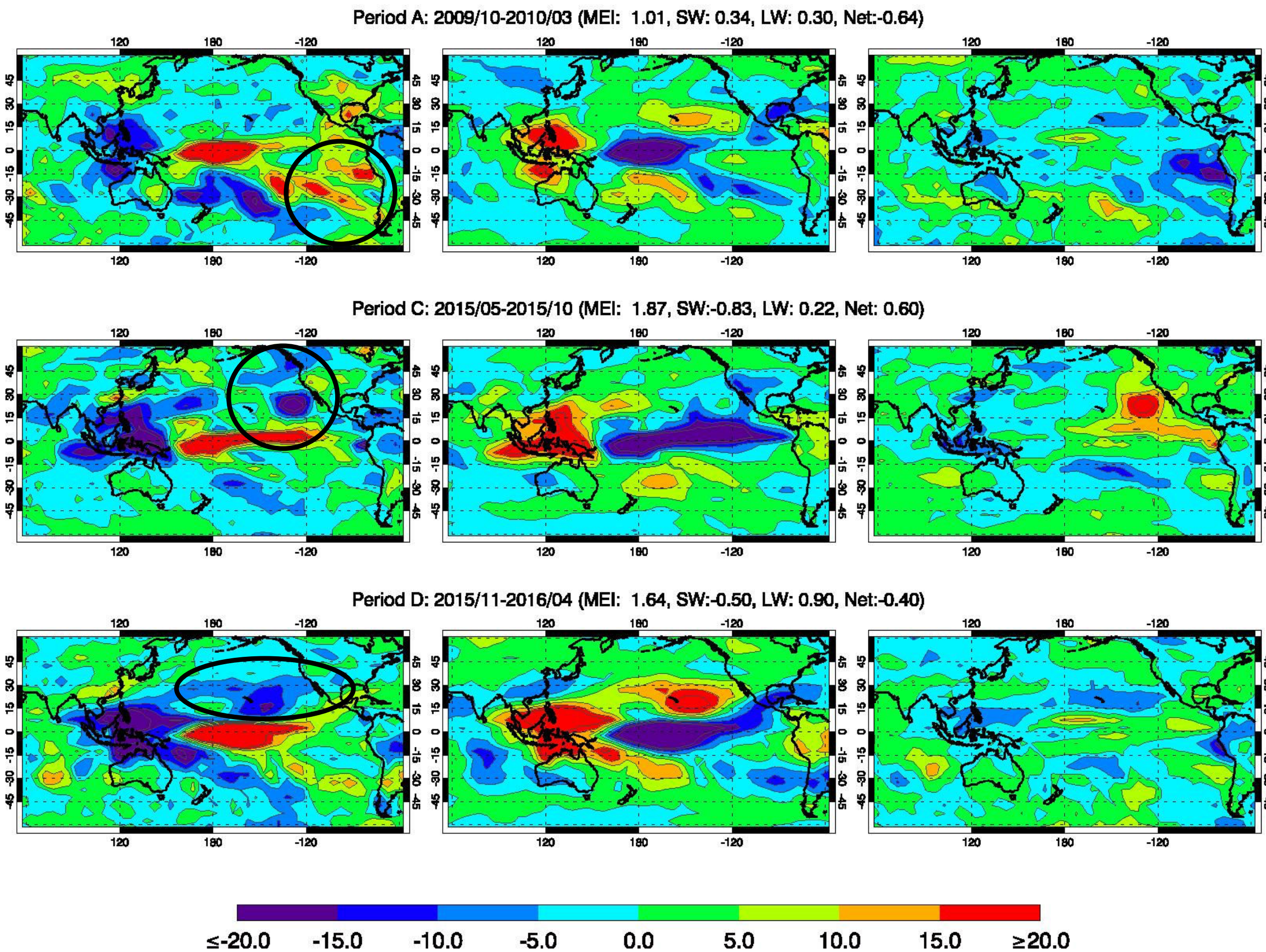


EBAF Flux Anomalies for the five periods

- ENSO events derive a shift of location of deep convective clouds, which causes maxima of SW and LW anomalies.
- However, deep convective clouds over the Warm Pool (during La Niña) or central Pacific (during El Niño) do not impact net anomalies much, since SW and LW anomalies mostly cancel out.
- In contrast, low-level clouds over the Eastern Pacific mainly drive net anomalies.

Why Are Net Anomalies Different between 2009/10 El Niño (Period A) and 2015/16 El Niño (Periods C & D)?

SW Anomaly | **LW Anomaly** | **Net Anomaly** | **Distinctive Features**



Period A
(2009/10 El Niño:
Oct 2009 – Mar 2010)

Low clouds increased over the SE Pacific.

Period C
(First Half of
2015/16 El Niño:
May 2015–Oct 2015)

Low clouds decreased over the NE Pacific.

Period D
(Second Half of
2015/16 El Niño:
Nov 2015–Apr 2016)

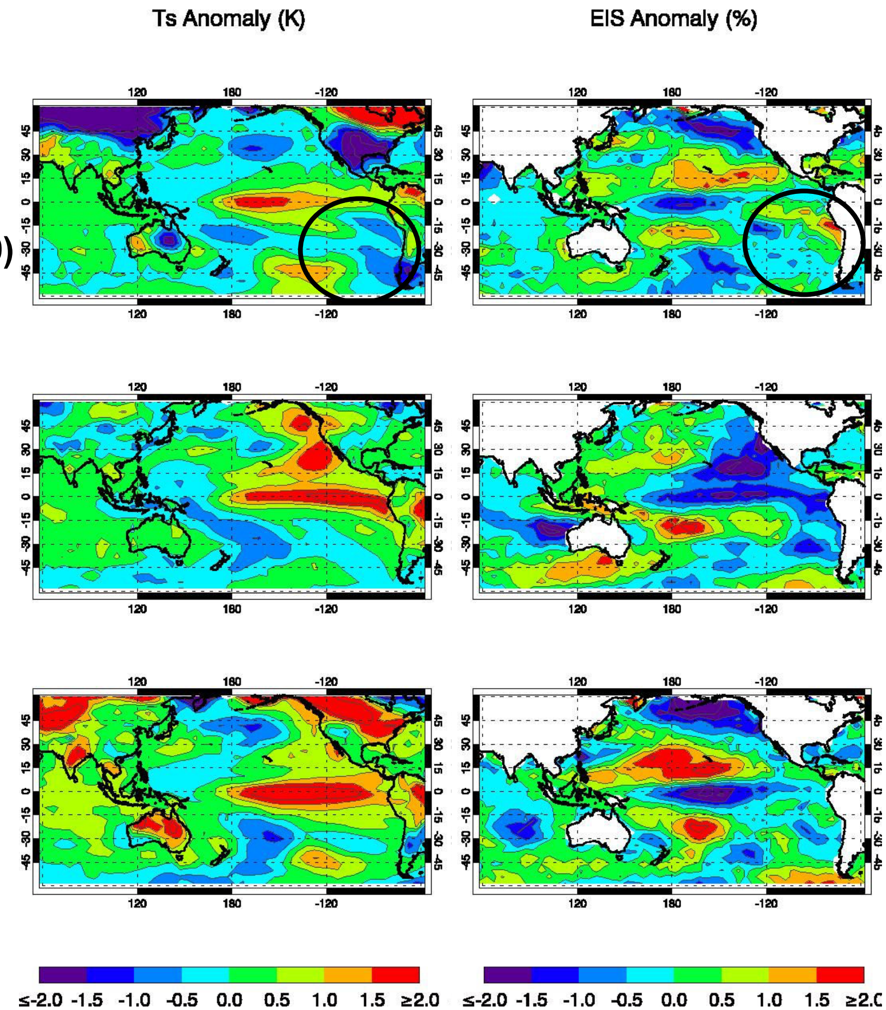
Mid/high clouds decreased over the northern Pacific with warmer surface emission.

MERRA-2 Temperature Anomalies in 2009/10 El Niño (Period A) vs 2015/16 El Niño (Periods C & D)

Period A
(2009/10 El Niño:
Oct 2009 – Mar 2010)

Period C
(First Half of
2015/16 El Niño:
May 2015–Oct 2015)

Period D
(Second Half of
2015/16 El Niño:
Nov 2015–Apr 2016)



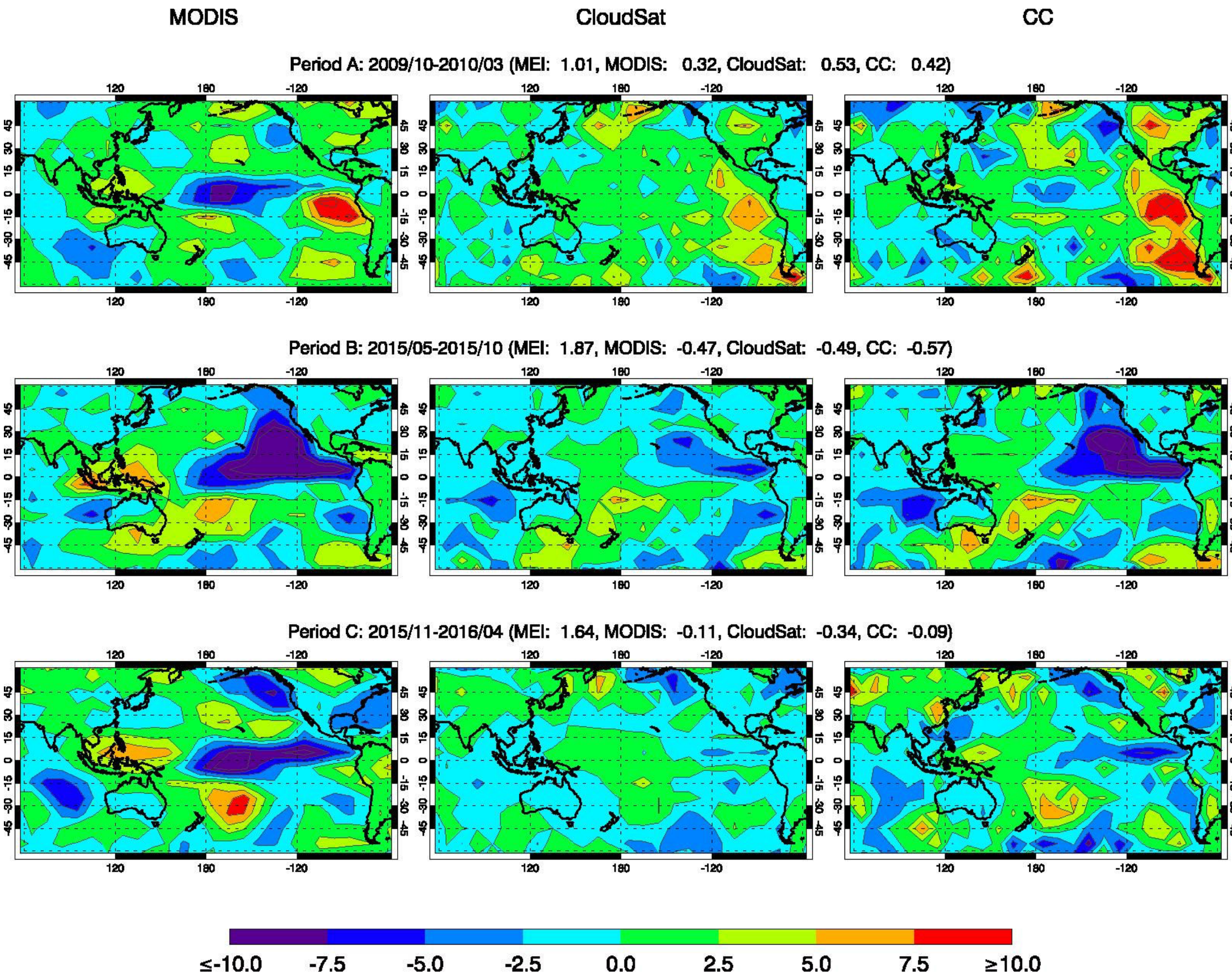
- During period A, cold SST anomalies remained over the southeastern (SE) Pacific and it provided a favorable condition for the low-level cloud generation.
- During period C and D, SST anomalies were positive over the eastern Pacific (EP).
- Two different types (central Pacific type El Niño vs eastern Pacific type El Niño) caused opposite signs of SST anomalies over the EP (Ashok et al., 2007; Kug et al., 2009; Yeh et al., 2009; Kao et al. 2009).

How Did the Satellite Measurements Capture Low Cloud Anomalies in 2009/10 El Niño (Period A) vs 2015/16 El Niño (Periods C & D)?

Period A
(2009/10 El Niño: Oct 2009 – Mar 2010)

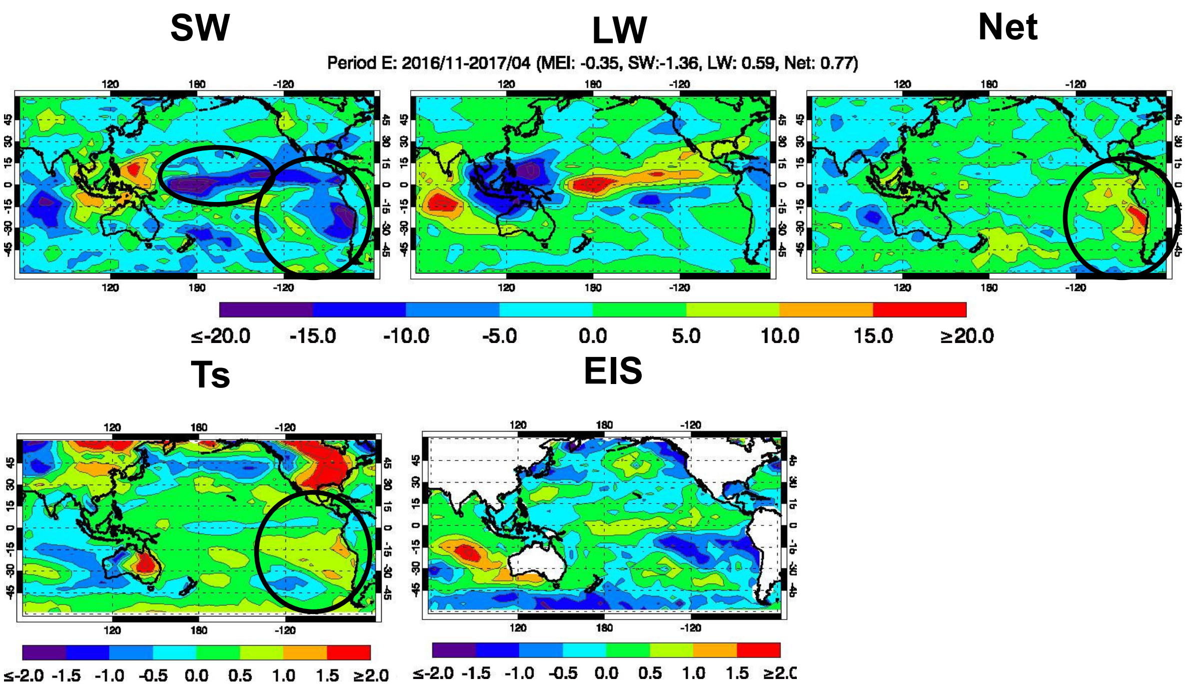
Period C
(First Half of 2015/16 El Niño: May 2015–Oct 2015)

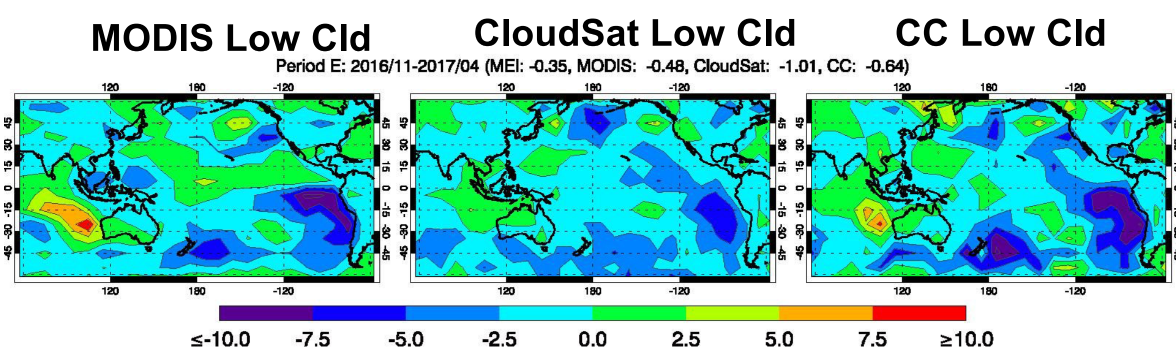
Period D
(Second Half of 2015/16 El Niño: Nov 2015–Apr 2016)



- CloudSat misses/ underestimates most of important low-level cloud anomalies.
- CALIPSO-CloudSat (CC) and MODIS low cloud anomalies agree well. These are strongly correlated with EIS anomalies.

How About Period E (Post 2015/16 El Niño: Nov 2016–Apr 2017)?

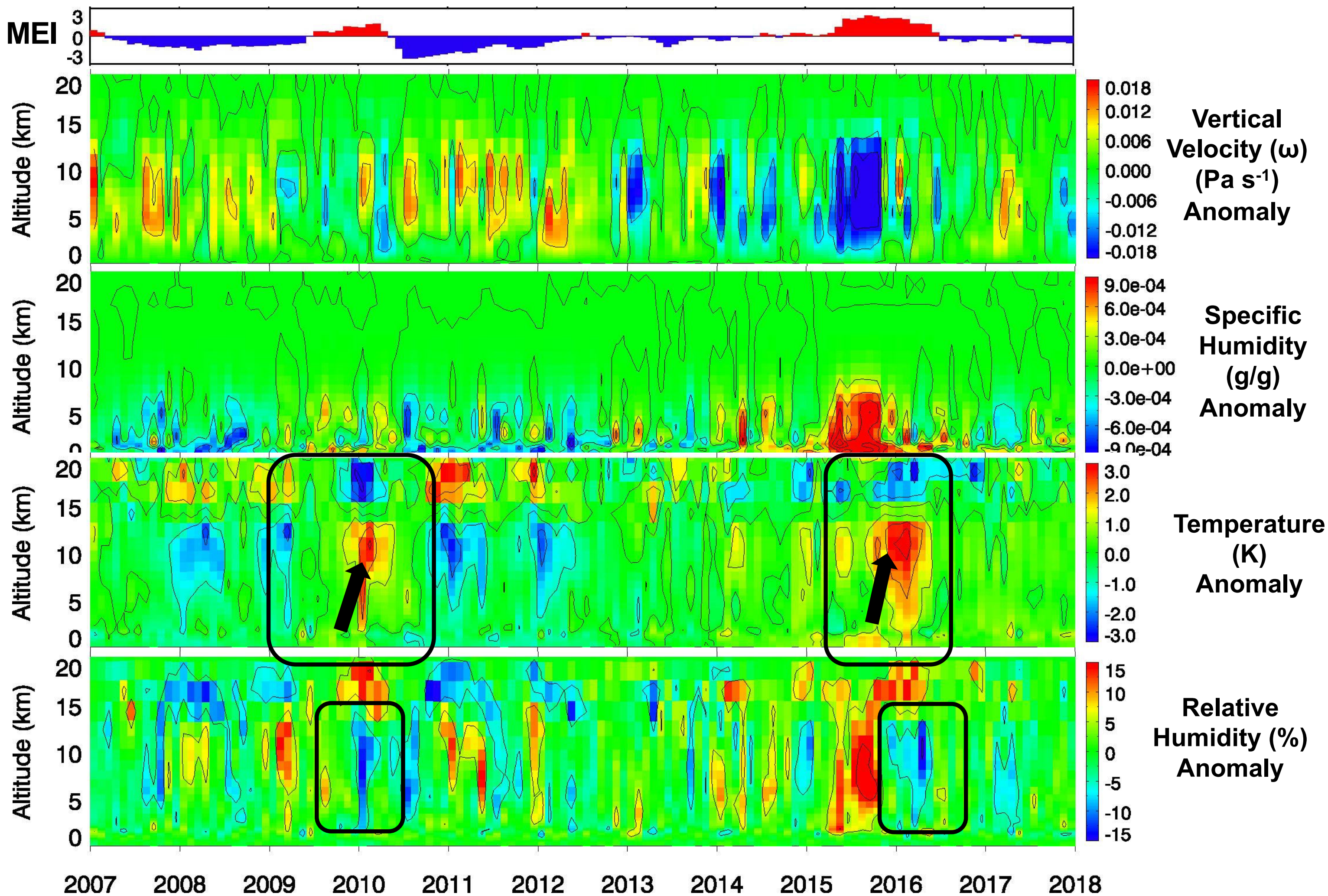




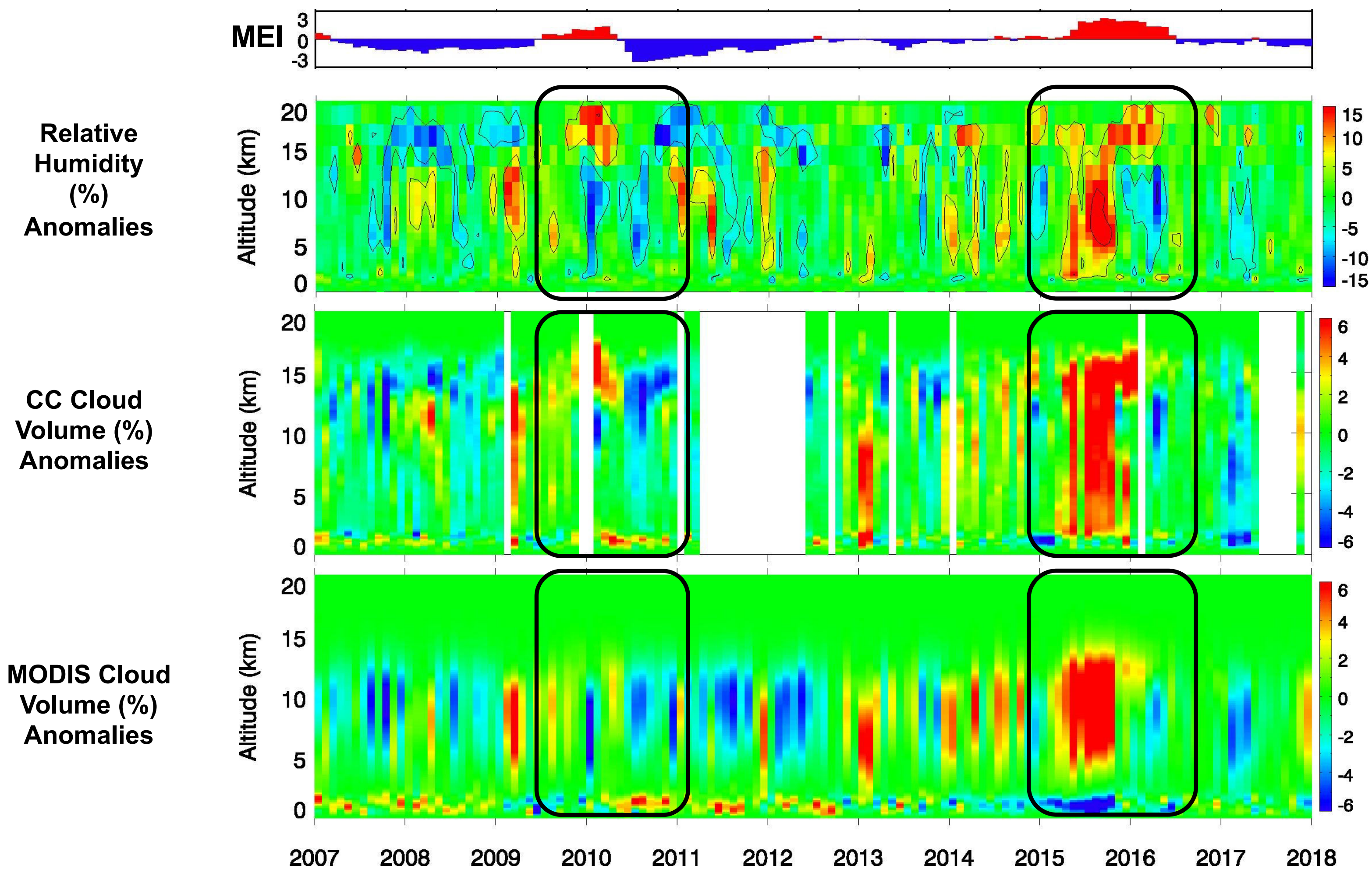
- The ENSO phase did not turn into La Niña phase (MEI index = -0.35), and the warm SST anomalies appeared over the southeastern (SE) Pacific.
- As a result, low-clouds decreased and net flux anomalies were positive.
- MODIS and CALIPSO/CloudSat (CC) captured this feature, while CloudSat had a smaller magnitude than other datasets.

Meteorological conditions over the NE Pacific (150W-120W, EQ-30N)

- During 2009/10 and 2015/16 El Niño seasons, negative ω, positive low-troposphere WV, and positive SST anomalies occur.
- After the warm SST anomalies, mid/upper troposphere (5-13 km) air temperature increased and tropopause temperature (13-18 km) decreased in the following spring. As a result, relative humidity decreased at 5-13 km, and increased at 13-18 km in the next spring.

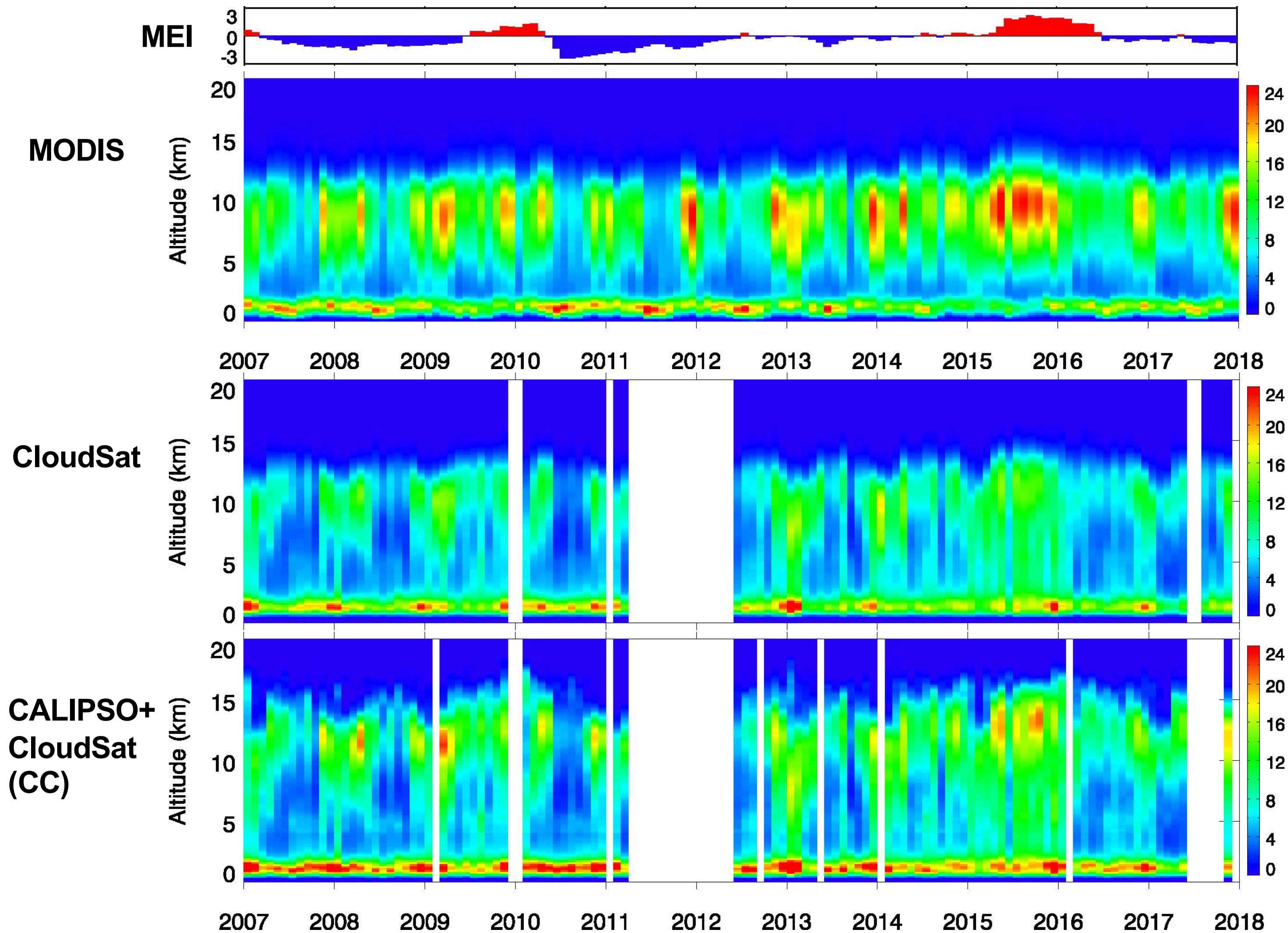


RH (%) versus Cloud Volume Fraction (%) Anomalies over the EP (150W-120W, EQ-30N)

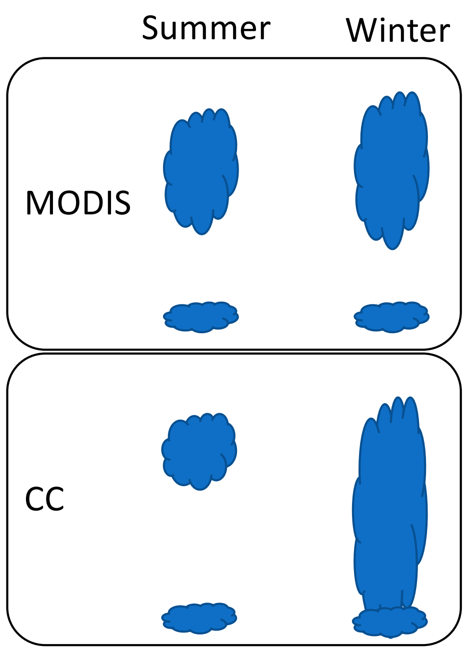


- Anomaly patterns of relative humidity (%) are well agreed with cloud volume anomalies.
- Particularly in the upper troposphere, CC merged cloud volume anomalies are better agreed with RH anomalies, compared to MODIS cloud volume anomalies.

Cloud Volume Fractions (%) over the Eastern Pacific (EP) (150W-120W, EQ-30N)



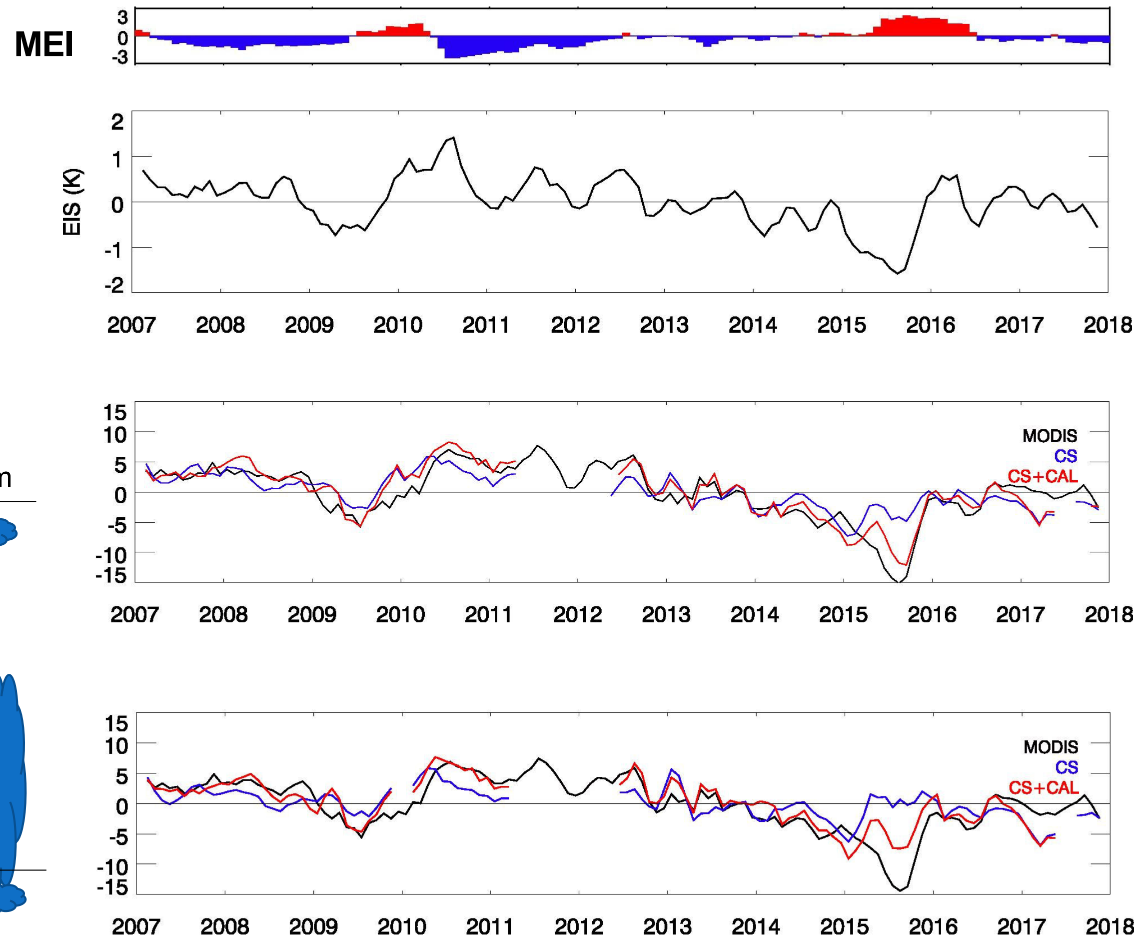
- The vertical gap between high/mid clouds and low clouds are different between CC and MODIS:



Low Cloud Anomalies (%) over the EP (150W-120W, EQ-30N)

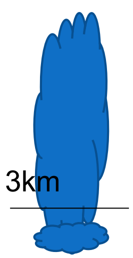
Smoothed with a 3-month moving window

EIS (K)



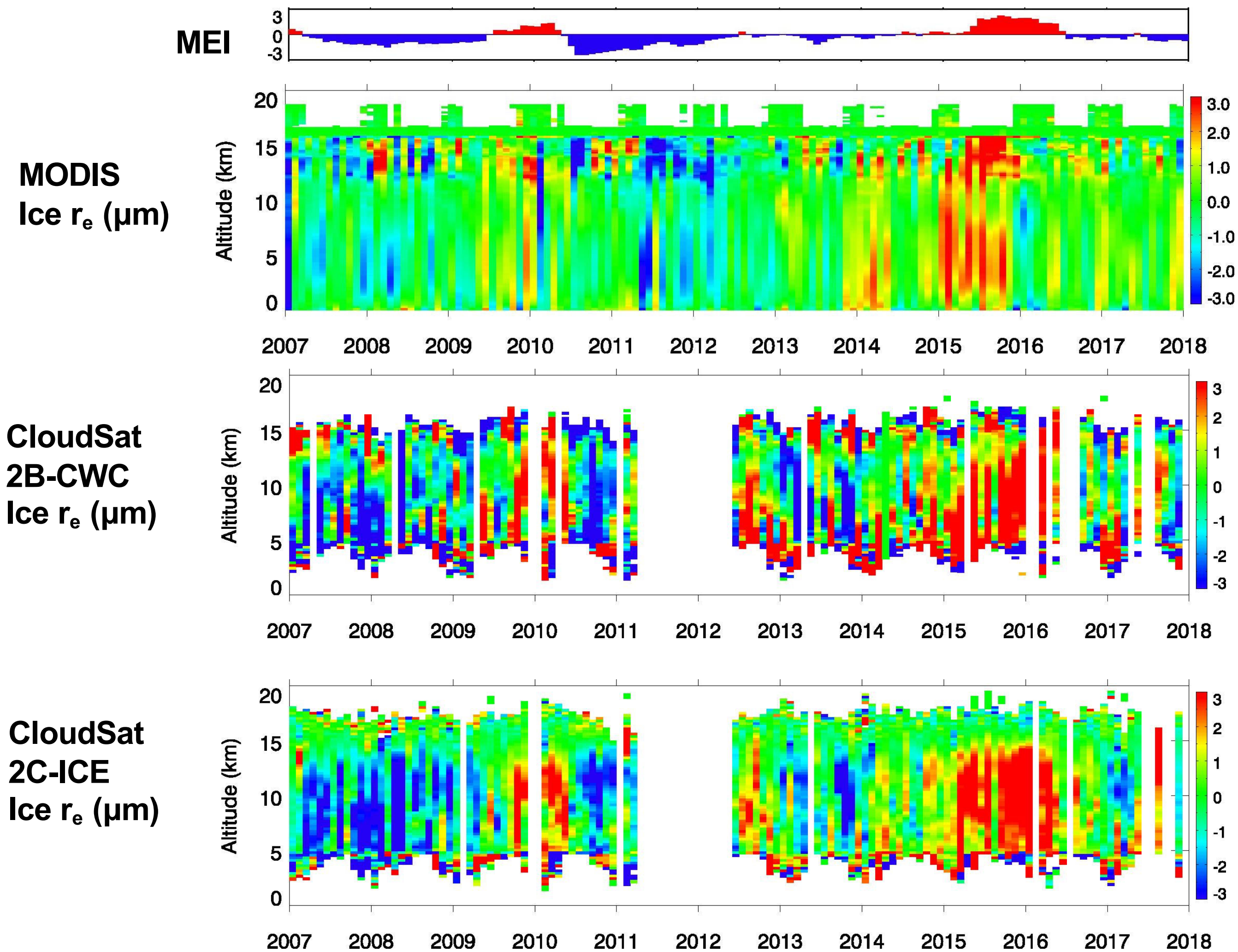
Anomalies of Occurrence (%) clouds with top heights below 3 km

Anomalies of occurrence of clouds between 0-3 km



- Low-level cloud anomalies are consistent between MODIS and CC if we only count low-level clouds with top below 3 km. These low-level cloud anomalies are well correlated with EIS anomalies.

- CC indicates that low clouds with cloud top height below 3 km were reduced during El Niño events due to negative EIS anomalies. However, mid- and high-level clouds were increased during the El Niño events, and the cloud amounts at 0-3 km altitude can be still be increased due to increased activity of mid and high clouds.



Ice Cloud Particle Size Anomalies over the EP (150W-120W, EQ-30N)

- Ice particle size got larger during 2009/10 and 2015/16 El Niño events, according to MODIS, CloudSat 2B-CWC and 2C-ICE.
- However, CloudSat data show the enlarged ice particle last longer until the later period of El Niño, while MODIS Indicates earlier decrease of particle in the later period of El Niño.

Conclusions

- The strong negative SW anomalies happened during 2015 are related to reduction of low-level clouds over the NE Pacific. This did not happen in 2009/10 El Niño because cold SST anomalies were prevalent over the EP.
- Combining CloudSat and CALIPSO has a large benefit in detecting low-level and high-level cloud anomalies.
- MODIS total cloud anomalies are consistent with CALIPSO-CloudSat combined anomalies, but cloud heights are different particularly for thin cirrus.
- Mid- and high-level cloud anomalies are well correlated with relative humidity (RH) anomalies.
- Low cloud occurrence with the cloud top height below 3 km is well explained by the estimated inversion strength (EIS). However, CALIPSO-CloudSat indicate that cloud base of mid/high level clouds stretched near surface and actual cloud amounts below 3 km are also affected by mid and high clouds.